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WATER CONSUMPTION

FOR HYDROGEN PRODUCTION

Hydrogen Energy Research Center

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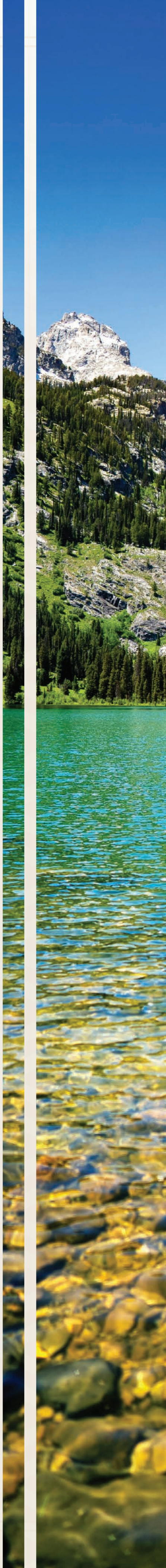

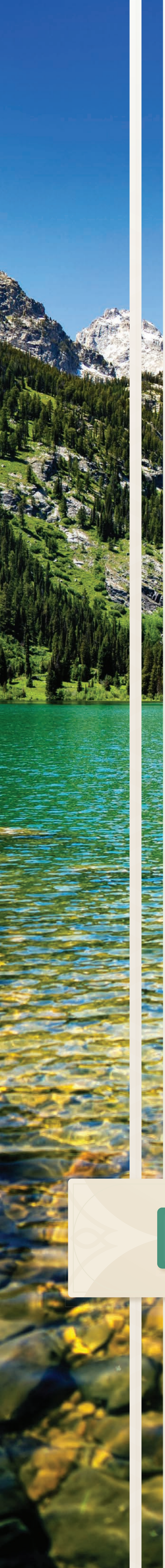

The purpose of this paper is to describe water use for five common methods of hydrogen generation. This paper will emphasize that these methods consume different amounts of water. Water is used as a reactant and in many supporting processes for hydrogen generation. When selecting a method for hydrogen generation operators should consider not only electrical and heat inputs required but also the amount of clean water needed.

There are five common ways to generate hydrogen: Steam Methane Reforming (SMR), Autothermal Reforming (ATR), Electrolysis, Coal Gasification, and Biomass Gasification. The most common among these is SMR, which produces 95% of all hydrogen globally.[1] Another widespread method is ATR which is very similar to SMR but performs the process in a pure oxygen atmosphere to improve efficiency. Electrolysis is the third most common and fastest-growing method because it can create carbon-free hydrogen.[2] Coal gasification was the earliest method of producing hydrogen during the Industrial Revolution but today ranks only fourth most common and is rarely used outside of China.[3] Like coal gasification, but even less commonly used; biomass gasification uses a high-carbon feedstock such as agricultural waste with water and converts the feedstock into hydrogen.[4]

In each of these methods, water is used as a reactant in the chemical reactions. The relative contribution of water and hydrocarbon feedstock to each kilogram of hydrogen output varies. SMR consumes 1.20 gals of water per kg of hydrogen produced.[5] This is quite water-intensive when compared to ATR which consumes only 1.01 gals.[6] Electrolysis, which generates hydrogen using only water uses 2.36 gal.[7] Coal gasification consumes only slightly less than 2.36 gals of water. Ammonia Synthesis Scenarios conducted by the National Energy Technology Laboratory (NETL) estimate about 1.14 gals of water per kg of hydrogen produced.[8] Moisture recovery, which depends on the specifications of the reactors used and their design in the gasification process, has a significant effect on the amount of water required for coal gasification. Fluidized bed and entrained flow reactors have a greater moisture content limit than some commonly industry standard reactors, like fixed bed reactors. In reactors with higher moisture content limits, the higher operating temperatures can facilitate the release of moisture from the feedstock, thereby potentially increasing moisture recovery. The amount of water for biomass gasification can vary widely depending on the type of biomass fuel used. The variability in water consumption among these methods reflects the ratio of output hydrogen that comes from water versus their respective hydrocarbon feedstocks.

Each of these 5 categories also requires water in supporting unit operations, which although they vary in detail all lead to water loss through evaporation, blowdown/bleed-off, and or drift. In every supporting unit operation that uses water, the primary loss of water occurs through evaporation. This leaves behind a higher salinity water in the system which must be compensated for through blowdown. Additionally, some water loss during evaporation occurs as an aerosol. The water loss in aerosol form is called drift. The following equation describes the relationship among these water losses.

$$\text{Blowdown} = \frac{\textit{Evaporative Loss} - \textit{Cycles of Concentration} * \textit{Drift Loss}}{\textit{Cycles of Concentration} - 1}$$

[1] Department of Energy Hydrogen Production: Natural Gas Reforming.
[2] World Resources Institute - Can Clean Hydrogen Fuel a Clean Energy Future?.
[3] https://www.sciencedirect.com/topics/engineering/coal-gasification
[4] World Resources Institute - Can Clean Hydrogen Fuel a Clean Energy Future?.
[5] Based on the chemical reaction calculations of SMR process considering the molecular weight of hydrogen, water and methane.
[6] Based on the chemical reaction calculations of ATR process considering the molecular weight of hydrogen, oxygen and water.
[7] Based on the chemical reaction calculations of electrolysis process considering the molecular weight of hydrogen, oxygen and water.
[8] https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/water-use-sng

Among all the supporting unit operations, cooling is the largest draw on water. The table below shows a maximum estimate of water demand for cooling of each hydrogen generation if only water were used for all cooling.

Water Loss in Cooling Process *Per Gallon of H_2 Produced*

Production Method	Drift (gal)	Evaporation (gal)	Blowdown (gal)	Total (gal)
Electrolysis	0.002	2.4	0.48	2.88
SMR	0.001	2.96	0.58	3.54
ATR	0.001	3.25	0.66	3.91
Coal Gasification	0.002	5.44	1.08	6.52
Biomass Gasification	0.004	4.09	0.82	4.91

However, water use is often reduced by running reactions at lower temperatures, taking advantage of natural heat radiation and convection, and or substituting some traditional water-fed heat exchangers for air-cooled or refrigerant-fed heat exchangers.

Empirical data shows that modern-day SMR unit operations draw an additional 1.58 -3.43 gals of water for all supporting unit operations. Because ATR is very similar to SMR its supporting unit operations are also expected to draw 1.58 -3.43 gals. Electrolysis does not require elaborate unit operations, so it only requires an additional 0.26-0.79 gals of water. Coal gasification requires significant water withdrawal for supporting unit operations that use an estimated 4.76 gals of water. Fortunately for coal and biomass gasification, although they may require more water to generate hydrogen, they can recover moisture from the raw carbon feedstock. The arriving wet coal feed may have 0-65 % of moisture recoverable. Lastly, biomass gasification is also water intensive with an estimated 2.38 gals of water used in supporting unit operations. Similarly, biomass can reasonably expect anywhere from 0-60 % of moisture recoverable from the feedstock. However, on average both can reasonably expect to recover approximately 40 % of moisture. It should be noted it is currently difficult to recover water from feedstock drying, but it may serve as a useful tool to offset partial water consumption in coal and biomass gasification and even so, water requirements are still relatively high compared to other methods. The following results can be seen in the table below.

Method	Gallons of H_2O Consumed *Per kg of H_2 Produced*	Gallon of H_2O Used in Supporting Devices *Per kg of H_2 Produced*	Estimated Potential H_2O Recoverable *Percentage from Raw Feed Stream*
Electrolysis	2.4	0.3 - 0.79	0
Steam Methane Reforming	1.2	1.59 - 3.43	0
Autothermal Reforming	1.0	1.59 - 3.43	0
Coal Gasification	≤ 2.4	≈ 4.76	≈ 40
Biomass Gasification	≤ 2.4	≈ 2.38	≈ 40

The five common hydrogen production methods require different amounts of water. During these processes, water is consumed as a reactant and withdrawn for supporting unit operations. When hydrogen generation is being considered, water should be considered as a valuable resource in the decision-making, and methods such as ATR may be a wise decision due to its lower water usage.


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